Reactor Boiler and Auxiliaries - Course 133

AUXILIARY CIRCUITS

The main types of heat transport systems have been discussed but considerations were only given to the circuit necessary to transport the heat from the fuel to the steam generator or turbine. Several auxiliary circuits are also associated with the main heat transport system. These may differ, in detail, according to what heat transport fluid is used but the function they serve is usually the same in most cases.

Standby Cooling

The main heat transport circuit is regarded as a highly reliable system for removing heat from the fuel under most circumstances. In a pressurized water system, for instance, there are spare pumps to improve reliability and, if all the pumps failed, natural convection or thermosyphoning would be adequate to remove fission product decay heat, provided that a heat sink in the form of a steam generator is available. Such a heat sink must, of course, be supplied with feedwater. However, even if the feedwater flow ceases, there is usually enough water in the steam generator to provide the required heat sink for 3 or 4 hours.

Since it is imperative that heat be removed from the fuel at all times, there are possible circumstances which make it necessary to provide an alternative heat removal system. These possible circumstances are:-

(1) The necessity of interrupting flow in the main heat transport circuit in order to isolate equipment for maintenance or because of leakage. Such isolation prevents forced or natural convection from occurring in an indirect cycle and an auxiliary heat removal system would be required.

(2) The loss of feedwater for a period long enough to exhaust the water already in the steam generator of an indirect cycle. A heat sink is no longer provided and natural convection can no longer continue.

(3) The necessity of having to cool the heat transport fluid, of an indirect cycle, below about 250°F. Since the water in the steam generator boils at 212°F, it cannot be used to cool the heat transport fluid below about 250°F. If lower temperatures are required (eg, for maintenance), then an alternative system is necessary.

(4) On turbine shutdown in a direct cycle. Steam flow and return feedwater flow are then interrupted and an alternative method of heat removal, from the fuel, is required.

Such alternative heat removal is possible by means of the purification system, which is considered later. Cooling of the heat transport fluid is usually necessary, in any case, before it is passed through ion-exchange columns and, so, the purification system could be designed as a standby cooling system as well. This arrangement, however, cannot be used with a direct cycle with an in-line purification system. In any case a separate standby or shutdown cooling system is simpler and provides greater reliability.

Figure 1 shows how reactor power decreases with time, following a reactor trip. It may be seen that, after about 80 seconds, power is produced almost entirely by fission product decay. This fission product power has decreased to about 1% of normal full power after about 3 hours. Further decrease of power is very slow and, therefore, the standby system should be capable of removing 1% of full reactor power over an indefinite period of time.

In the event that rapid isolation of the main circuit is required because of leakage, such isolation would probably be carried out immediately following the circulating pump rundown time. The reactor thermal power is still likely to be about 5% of full power, or higher, at this time and the standby system must be able to cope with this emergency condition. When the standby system is normally put into operation, the heat transport fluid temperatures will be between 200°F and 300°F but, under the emergency conditions outlined above, these temperatures are likely to be in excess of 500°F. Stresses resulting from these high temperatures make it undesirable to use the system, in this manner, too frequently.

A typical standby circuit is shown in Figure 2. It consists simply of a circulating pump, a heat exchanger, isolating valves and associated piping. The requirements of equipment and piping are similar to those for the main system. The heat exchanger would probably be of the U-tube, tube-and-shell type with monel or inconnel tubes and carbon steel shell. If heavy water is used in the heat transport system, double tube sheets would likely be used and the tubes welded to the tube sheets.

When the main system is in operation the standby circuit must be isolated. Conversely, when the standby system is in operation flow must be prevented through the main circuit, otherwise flow through the reactor is by-passed. The power supply to the pumps and the cooling water supply to the heat exchanger must be the most reliable available. The pumps would therefore, be supplied from Class III power (ie, Diesel generator

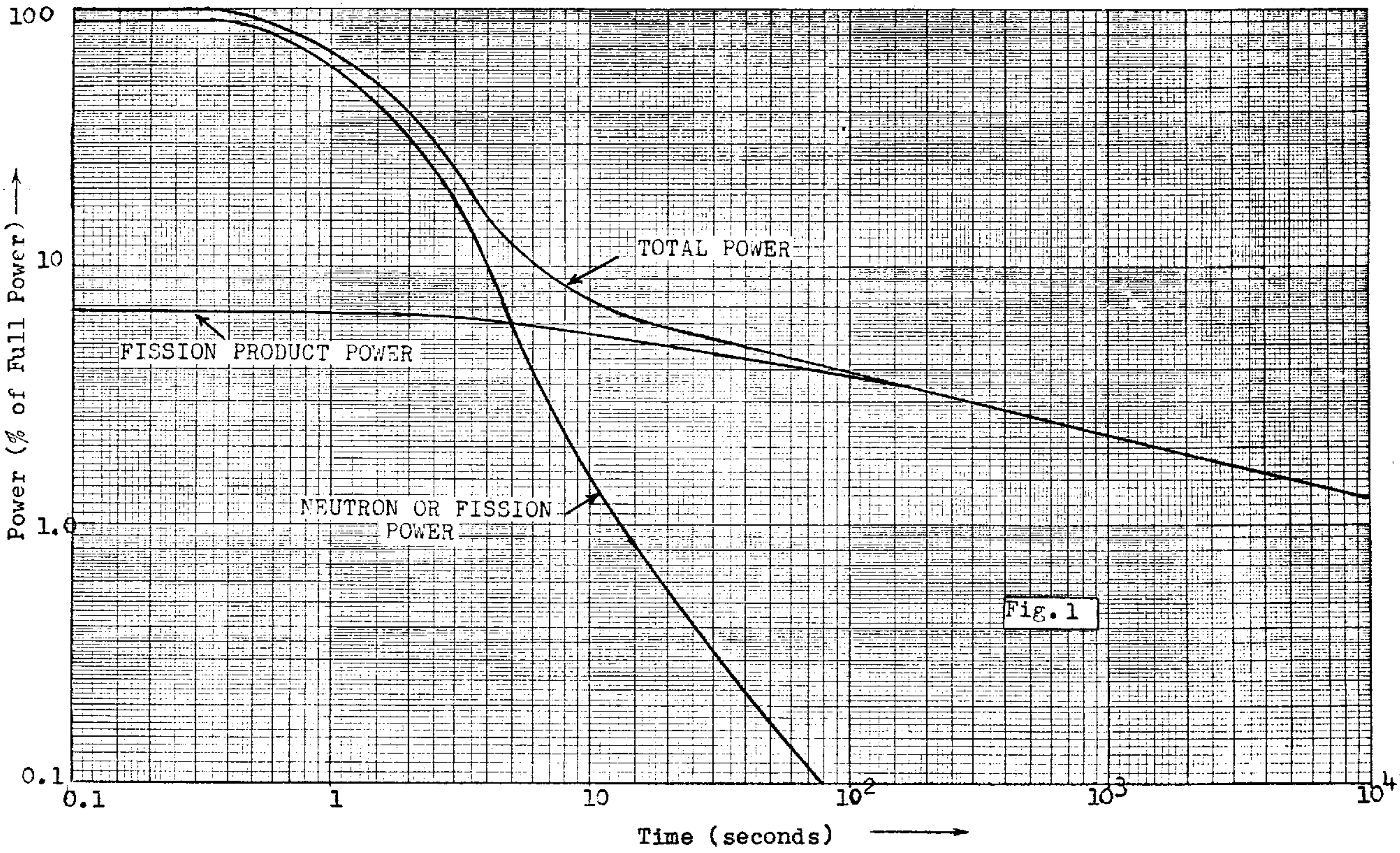
100
10
1.0
0.1
Power (% of Full Power) ⟶
0.1
1
10
10^2
10^3
10^4
Time (seconds) ⟶
TOTAL POWER
FISSION PRODUCT POWER
NEUTRON OR FISSION POWER

Fig. 1

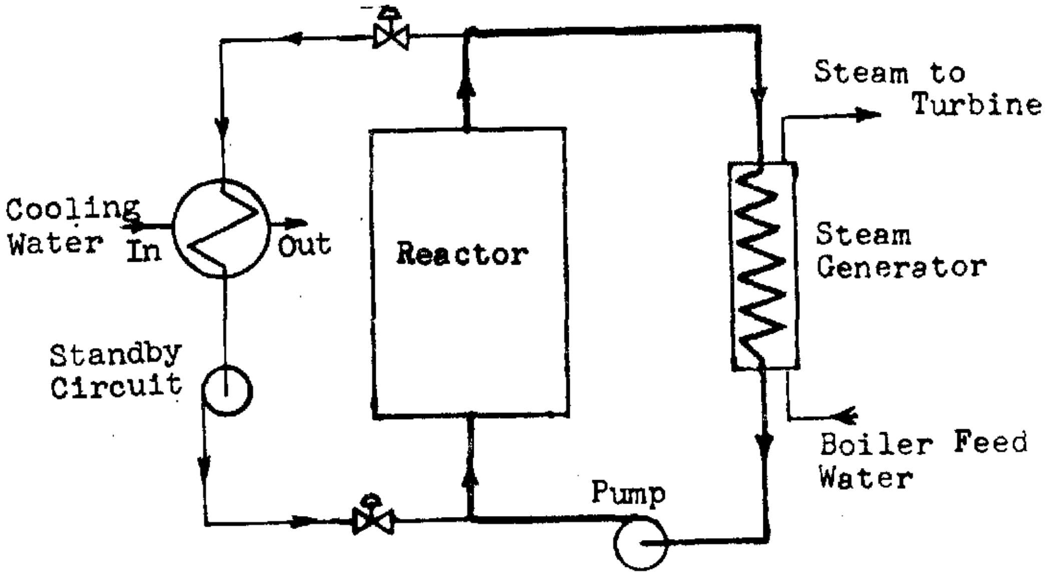

Fig. 2

back-up). The cooling water would normally be supplied from the process water system, but in the event of failure of this supply, cooling water would be provided from a gasoline pump.

Figure 3 shows a dual arrangement of standby circuits that could be used with a horizontal pressure tube reactor of the CANDU type.

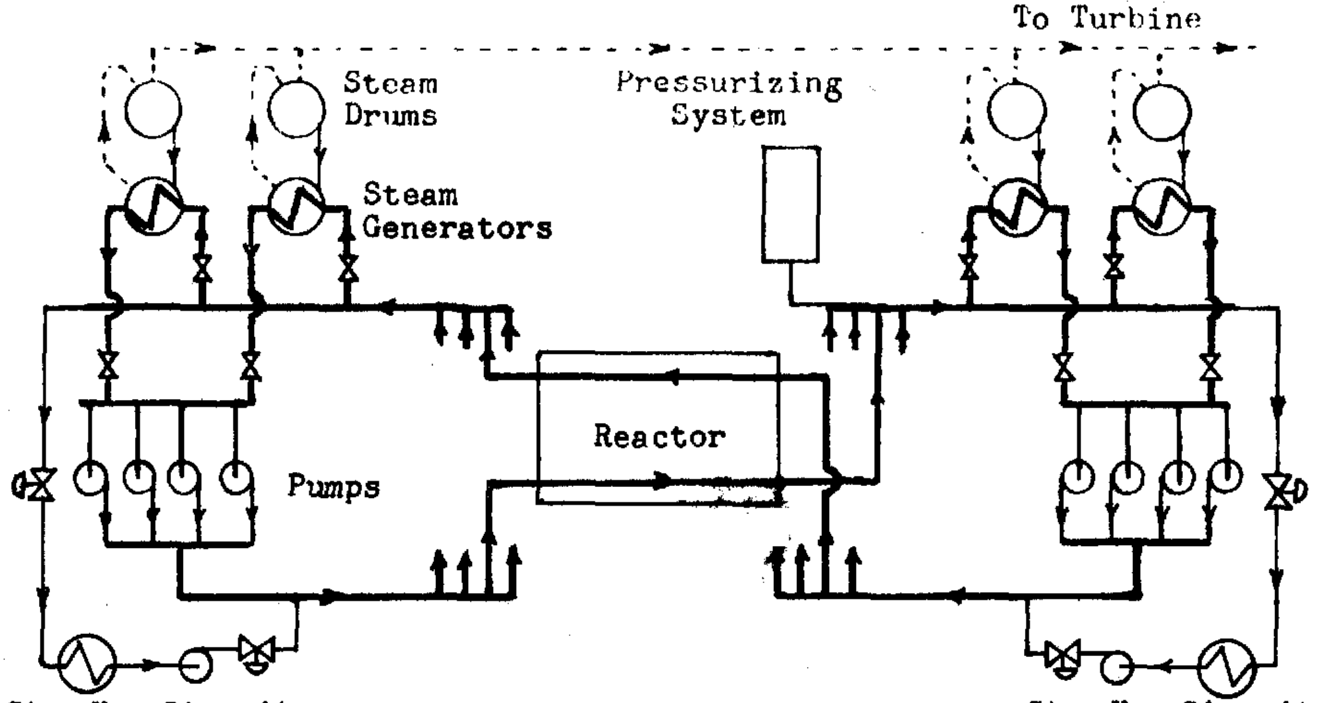

Fig. 3

Again flow through the main system must be prevented when the standby circuits are in operation.

Purification and Degassing Systems

These systems are being considered together because one common system is occasionally used for both purposes. As in the case of moderator purification, the heat transport purification is used to remove corrosion products and to control the pH or pD of the heat transport fluid.

In pressurized water systems the purification system is frequently a separate by-pass system, as shown in Figure 4. The requirements of the system and the design features which meet these requirements are as follows:-

(1) The heat transport system is at a temperature of approximately 500°F whereas the temperature at the ion exchange units should be 120°F or lower. Also the purified water leaving the ion exchange columns should have its temperature raised before being returned to the heat transport system. Both of these requirements are, at least partially, met by using the regenerative heat exchanger in the circuit. Water, from the heat transport system, enters the purification system through the tube side of this heat exchanger. Water returning to the heat transport system, from the purification system, passes through the shell side of this regenerator. Some of the heat from the heat transport fluid is, thereby, transferred to the returning fluid, the temperature of which is, therefore raised before it is returned to the main system. Further cooling of the system water may well be necessary, in a second heat exchanger, C, before it can be passed through the ion exchange columns, IX. The specifications for both heat exchangers would be similar to those for the heat exchanger in the standby circuit.

(2) The heat transport fluid pressure will be in excess of 1000 psig., whereas the ion exchange columns can withstand around 100 psig if standard units are used. A pressure reducing valve, V, is, therefore, required in the purification system. Excessive flashing would occur at this valve if the regenerative heat exchanger was not used to cool the water. The valve V may also be used to regulate the flow.

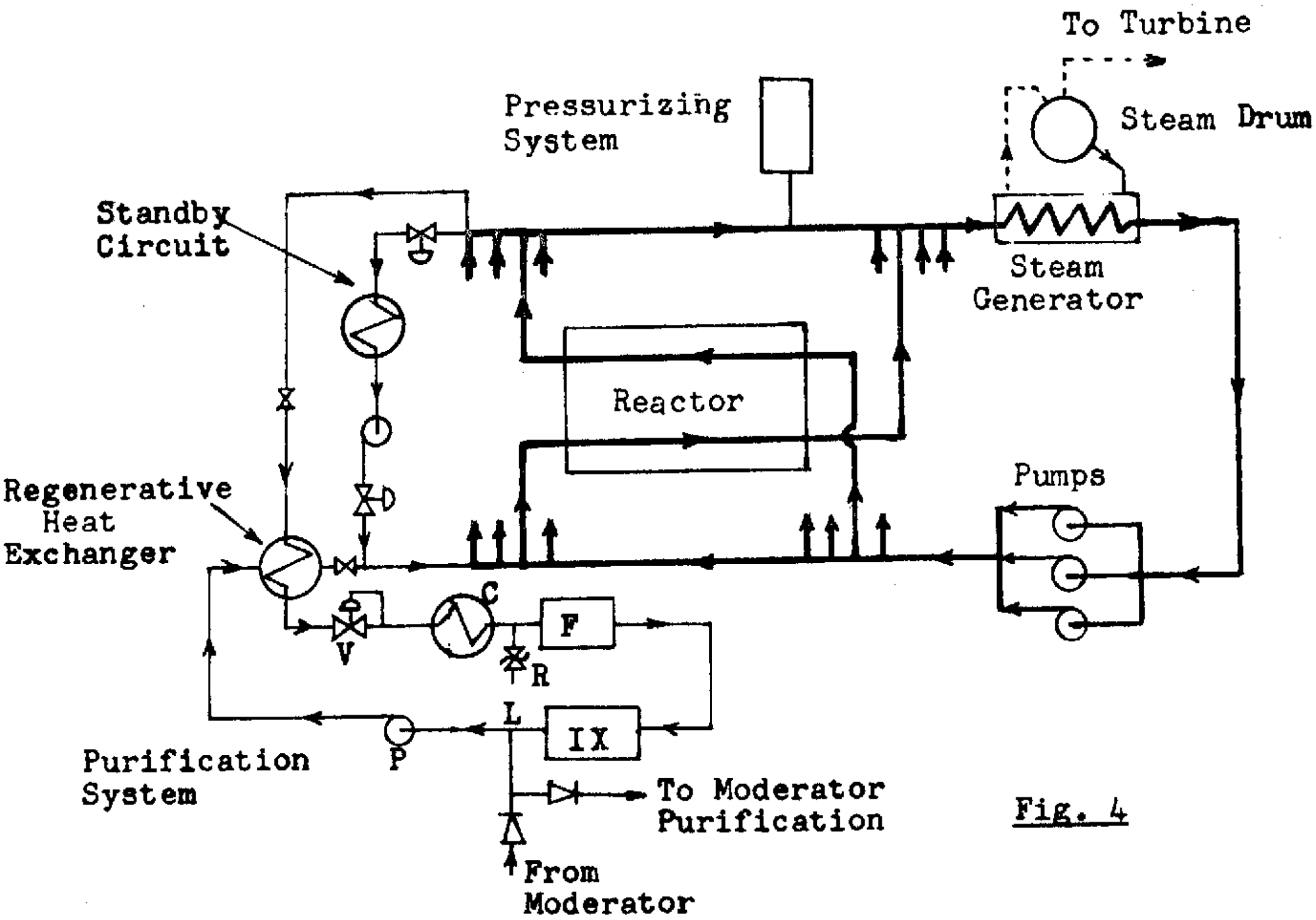

Fig. 4

(3) The crud level or particulate material concentration is likely to be higher in the heat transport system than in the moderator system, described previously, particularly when the system is initially operated. A filter, F, would therefore, be required either as a temporary arrangement, during initial operation of the heat transport system, or as a permanent fixture if the particulate concentration causes blocking of the ion exchange columns. A permanent filter could be of the backwashable or disposable type.

(4) A mixed bed resin would be used in the ion exchange column. Since the heat transport system would be predominently of carbon steel construction, a pH of 9.5 to 11 is required in the system. The cation resin would, therefore, be in the lithium form, the lithium exchange maintaining the desired pH. Supplementary addition of lithium hydroxide to the main system may also be required. Two such ion exchange columns, installed in parallel, would facilitate resin changing.

(5) The circulating pump, P, is sized to provide a flow of 40 Igpm to 50 Igpm. The pump discharge pressure must be greater than the main system pressure.

(6) Overpressurization of the filter and resin beds is prevented by means of the relief valve R.

When a system, such as this, is used for purification, some gas is likely to come out of solution because of the large drop in pressure that occurs. Some arrangement must be provided for venting at the highest points in the system. These gasses could, normally, be vented into the ventillation system exhaust. However with heavy water heat transport fluid, the gasses would be vented into the collection system so that the heavy water vapour can be recovered. It is also possible that fission product gasses may be present because of fuel sheath failures. Therefore, consideration must be given to venting into a delay tank, where the fission product gas activity can be allowed to decay, even with a light water system.

Water, under irradiation, dissocates into hydrogen and oxygen. However, as was mentioned earlier in the course, this dissociation is inhibited if there is an excess of hydrogen dissolved in the water. Such a condition can be achieved by removing the oxygen from solution or by adding hydrogen. Some oxygen will be removed through corrosion but a degassing system may be considered to remove the remainder. The same degassing system may be required to remove fission product gasses released during fuel sheath failures or to remove helium which may find its way into a heavy water heat transport system from the moderator. It is also possible that the hydrogen may be absorbed in zircalloy and cause embrittlement and that the hydrogen concentration may have to be controlled. These gasses can be removed in a degassing tank located in the purification system after the ion exchange columns. Such a tank would be vented to a delay tank and, if a heavy water heat transport fluid is involved, provisions would be made to recover the heavy water vapour (see Relief System consideration). An alternative method of degassing is available when pressurization of the main circuit is by means of a pressurizing tank containing electric heaters, as shown in Figure 5. The sprays in the tank can be used for continuous pressure control and degassing. As gas accumulates in the tank it can be released to the delay tank through the valve C.

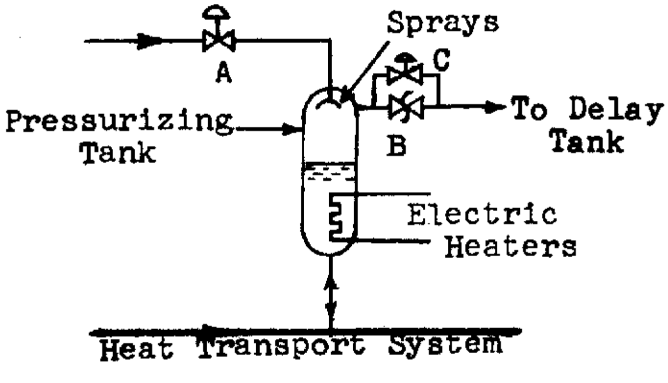

Fig. 5

Any degassing arrangement will, inevitably, take the deuterium out of solution, if the heat transport fluid is heavy water. This not only, encourages further radiolytic decomposition of the water, but also represents a loss of heavy water. A recombination unit might, therefore, be required to recover the deuterium and more deuterium or hydrogen may have to be injected into the heat transport fluid to inhibit further decomposition. Practical experience at NPD G.S. has indicated that a minimum of degassing has been required because little or no fission product gasses have been released and the oxygen has been removed without degassing. The deuterium has also been removed from solution and more deuterium has had to be added from time to time.

The feed and bleed system of pressurization can be design to incorporate both a purification and a degassing system, as shown in Figure 6. A continuous bleed and feed flow is passed through the ion exchange column and the degasser. If a feed flow, in excess of the normal flow, is required because of contraction in the main circuit, due to cooling, the feed pump obtains additional suction supply from the water storage tank. If faster bleed flow than the normal flow is required, because of swell, in the main heat transport circuit, the relief valve opens, at a predetermined pressure, to allow direct flow to the storage tank. Facilities are provided to valve out and by-pass either the ion exchange column or the degasser.

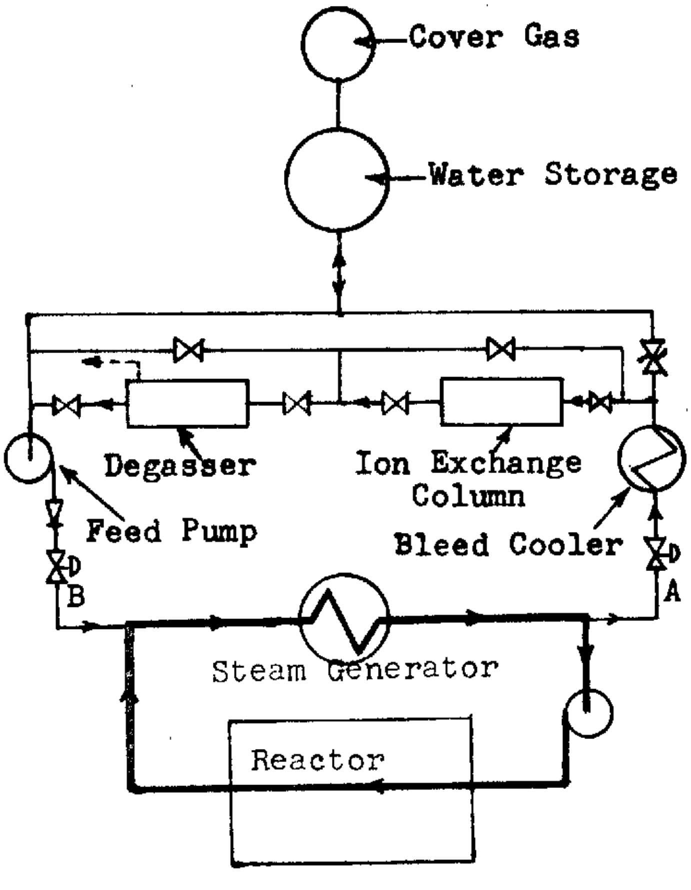

Fig. 6

The degasser is usually a packed column in which the pressure is kept as low as possible. The water to be degassed enters the top of the column and is stripped of gas by a small flow of heavy water vapour which enters the column at the bottom. The vapour and off-gasses, from the top of the column pass into the off-gasses system. Here the off-gasses are separated from the vapour and are passed through a recombination unit, (if deuterium has to be recovered), and into a delay tank, before being bled off into the ventillation exhaust system.

Most of the U.S. boiling water reactors, using the direct cycle, have the same type of purification and degassing system as that shown in Figure 4. The water entering the system is taken from the lowest part of the reactor vessel where the water is coolest. The purified water is then fed into the feedwater inlet to the reactor. Alternatively, the purified water can be returned to the turbine condenser or to the suction of the condensate pumps. The direct cycle system permits an in-line purification system to be used, whereby the ion exchange columns are placed in the condensate lines from the turbine condenser. It is possible that the pH may be controlled by ammonia injection into the feedwater rather than by lithium ion exchange.

When gas is used as the heat transport fluid, it is purified in a simply by-pass circuit which takes about 2% of the main system flow. The most troublesome impurities are dust and moisture. The dust is removed with filters and the moisture removed with driers. If gaseous impurities are present in carbon dioxide they can be removed by distillation at reduced temperatures. Gaseous impurities in helium are removed by molecular sieve CO_2 adsorbers, and catalytic $CO - H_2$ converters.

When organic liquids are used as the heat transport fluid, radiolytic damage causes formation of gasses and high molecular weight compounds, which are called HIGH BOILERS. The high boiler concentration is allowed to reach about 30% in order to reduce radiolytic damage. However a purification system is required to maintain this high boiler concentration. A degassing system is also required to remove the gasses. Figure 7 shows a typical degassing and purification arrangement. As seen from the figure both degassing and purification systems are by-pass systems.

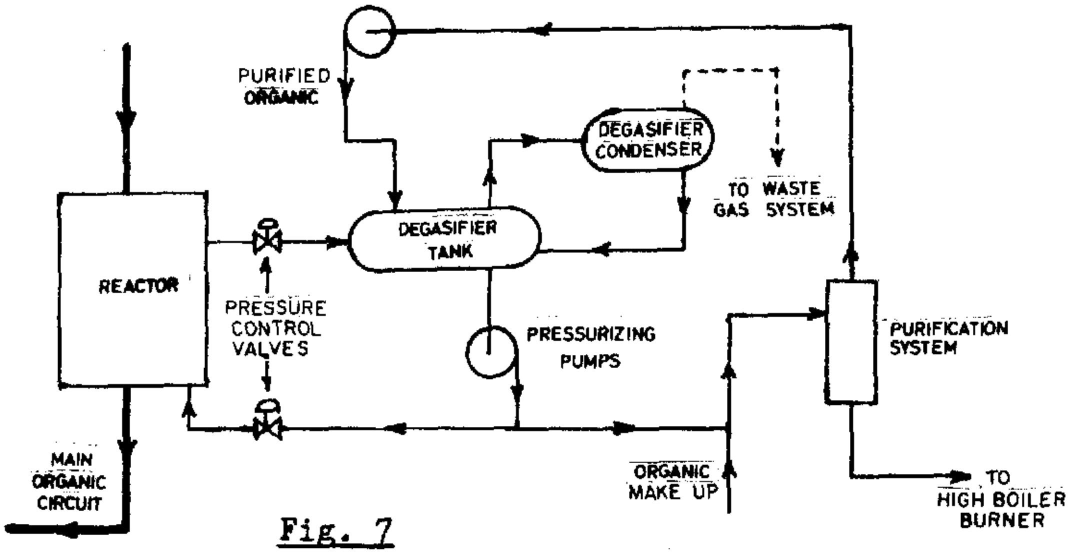

Fig. 7

The gasses and water

vapour are removed in the degassifier tank, into which the hot organic fluid is sprayed under vacuum. Organic vapours are condensed in the condenser and returned to the system. The gasses are vented to the ventillation exhaust system through the waste gas system. The organic is returned to the main system through the pressurizing pumps, which also produce whatever pressure is required in the system. This pressure is controlled by the pressure control valves.

A small fraction, (about 0.5 gpm), of the pressurizing pump discharge is fed to the purification system. This is a continuous distillation column in which the organic fluid is distilled under reduced pressure. The purified coolant is taken from the top of the column and returned to the degassified tank, and thence, to the main system. The residue from the bottom is mainly high boilers and activated products. These are stored until the radioactivity has decayed sufficiently and then burned in a hydrocarbon burner.

The organic fluid make-up is also processed through the purification system, to remove impurities, before being added to the main system.

In order to prevent corrosion and the plugging of pipes in a liquid sodium system, due to deposition of sodium oxide, the oxygen content in sodium must be kept below 10 ppm. The control of the oxygen content is accomplished by cold trapping or by high temperature "gettering" processes. The cold or hot traps are arranged in bypass circuits, as shown in Figure 8.

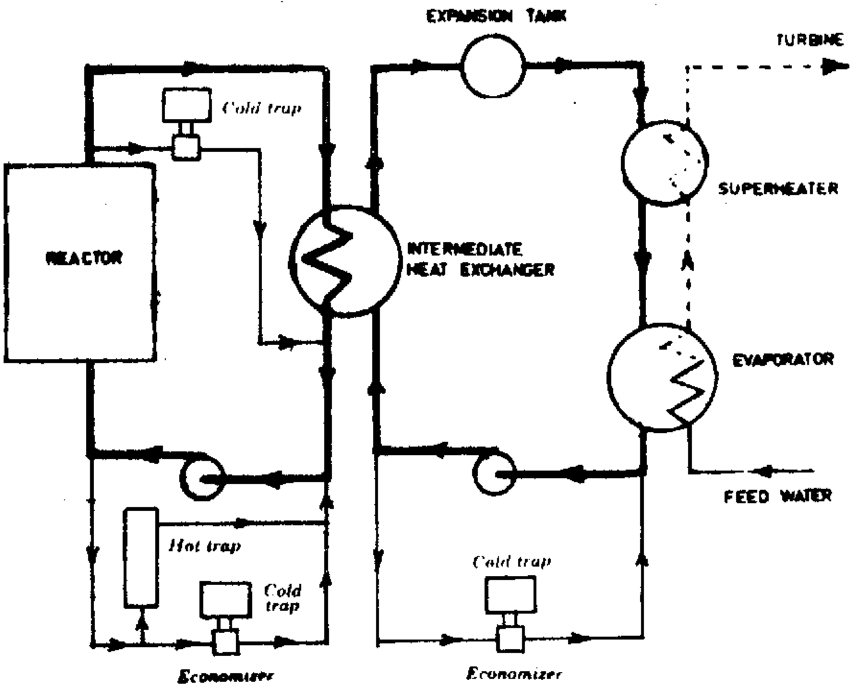

Fig. 8

Cold-trapping involves a reduction in the temperature of the sodium to the point where sodium oxide precipitates and can be filtered out. Figure 9 shows design details of a cold trap in which boiling toluene is used to lower the temperature of the sodium. The sodium oxide precipitates out on the steel mesh screens. Hot-trapping involves the use of a material, such as zirconium, which has a marked affinity for oxygen at very high temperatures. Such a hot trap is shown in Figure 10.

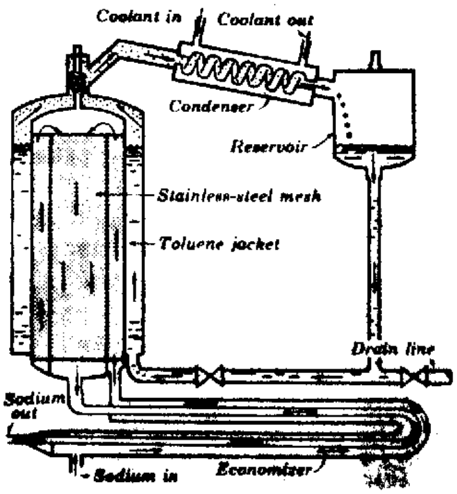

Fig. 9

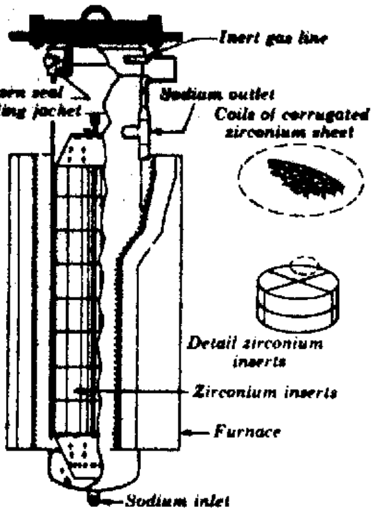

Fig. 10

Constant Volume Control and Emergency Injection

Since it is imperitive that heat must be removed from the fuel at all times, under no circumstances can the fuel be allowed to become uncovered. There are three possible conditions which could result in the fuel becoming uncovered and thereby prevent effective heat removal from the fuel:-

(a) Contraction of the main heat transport system due to a decrease in the system temperature on reactor shutdown.

(b) Small losses of fluid from the system through sampling, purification or monitoring systems or through leakage.

(c) Gross loss of fluid from the system because of a rupture in the heat transport system.

The first two sets of circumstances occur as a result of normal operation of the system, whereas the third may be considered an emergency situation.

In reactors using the pressure vessel concept enough fluid is present, above the core in the reactor vessel, to accomodate changes in volume that occur as a result of changes in temperature. With organic or liquid metal heat transport fluid a big enough pool of the fluid exists above the core to fill the core in an emergency.

When light water is used as a heat transport fluid small losses of liquid are easily made up through the valve, A, in Figure 11. The valve A would open on change in level either in the pressurizing tank or in the reactor. The supply to valve A must, of course be pressurized.

If a rupture in the heat transport system results in large losses of system water, emergency injection of water would occur through check valves into either or both inlet and outlet headers or into the steam drum and the inlet header of a direct cycle system.

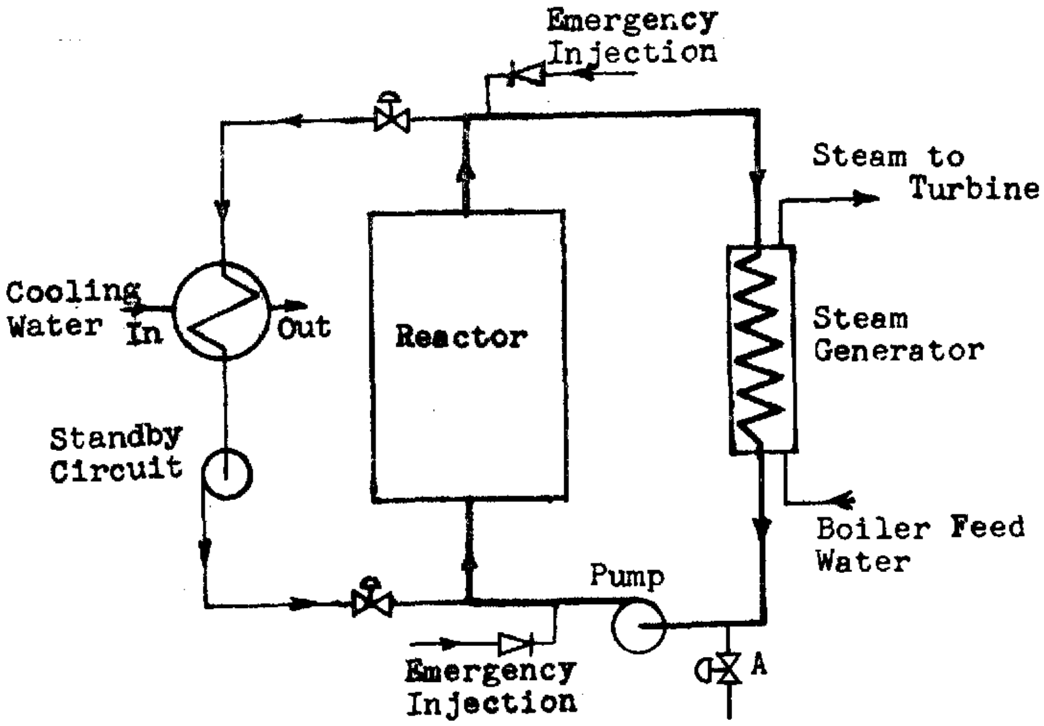

Fig. 11

The emergency water supply would come, initially from a storage tank. This supply would provide time for the system to be connected to a more continuous source of water, such as the process water system.

In a heavy water pressure tube system, pressurized on the feed and bleed principle, the system is solid. Swell or contraction in the system cause changes in pressure before changes in volume occur. The feed and bleed pressurizing system correct these pressure changes by addition or subtraction of water and no other separate system is required. Small losses are made up from the heavy water storage tank through the feed pumps.

When a pressurizing tank is used to pressurize the system, the most sensitive indication of a volume change in the system is the water level in the tank. A drop in level in the tank could cause a valve, such as valve A in Figure 11, to open and allow make-up water into the system. However,for such an arrangement to work at all, a supply of pressurized heavy water has to be available. The most convenient source of heavy water is the moderator system, and valve A could be supplied from the moderator system through a high discharge pressure pump.

Swell, in such a system would cause the pressurizing tank level to rise and level signals could be used to open a second valve and allow water into the moderator system. However, there are disadvantages to using such valve arrangements:-

(a) The moderator is at a lower temperature than the heat transport system and would cool it down if admitted directly into the system through valve A.

(b) The heat transport system is hotter than the moderator system and the quantity of water transferred during a swell would substantially increase the required cooling capacity of the moderator heat exchanger.

(c) The heat transport system is at a higher pD than the moderator and so water transferred to the moderator system has to pass through the moderator purification system. This last requirement however, is inevitable whatever transfer method is used, but it does mean that the water pressure must be reduced before it enters the moderator purification system.

All the above disadvantages can be overcome by transferring water in either direction through the heat transport purification system, as shown in Figure 12. Flow of water out of the heat transport system is controlled by valve V_1 and return flow to the heat transport system is controlled with V_2. During normal operation of the purification system V_1 allows 40 Igpm flow through the ion exchange column. The pump P_1 returns to the system 40 Igpm plus whatever water is required to make up the losses from the system and valve V_2 permits this flow into the system. The additional water is obtained from the moderator system, through a check valve, at the point L.

If the level in the pressurizing tank falls, due to contraction or small leaks, the valve V_1 closes and V_2 opens to permit make up water to be pumped from the moderator system. This water will be heated in the regenerative heat exchanger before entering the heat transport system. If the drop in level is sharp or it continues to fall a second pump, P_2, may be used, with a higher capacity than P_1, to provide additional make-up volume. If the level in the tank rises due to swell in the heat transport system, V_2 closes to prevent return of water to the system and water flows to the moderator system through the moderator ion exchange columns. This water has already been depressurized, by V_1, and cooled in the heat exchangers.

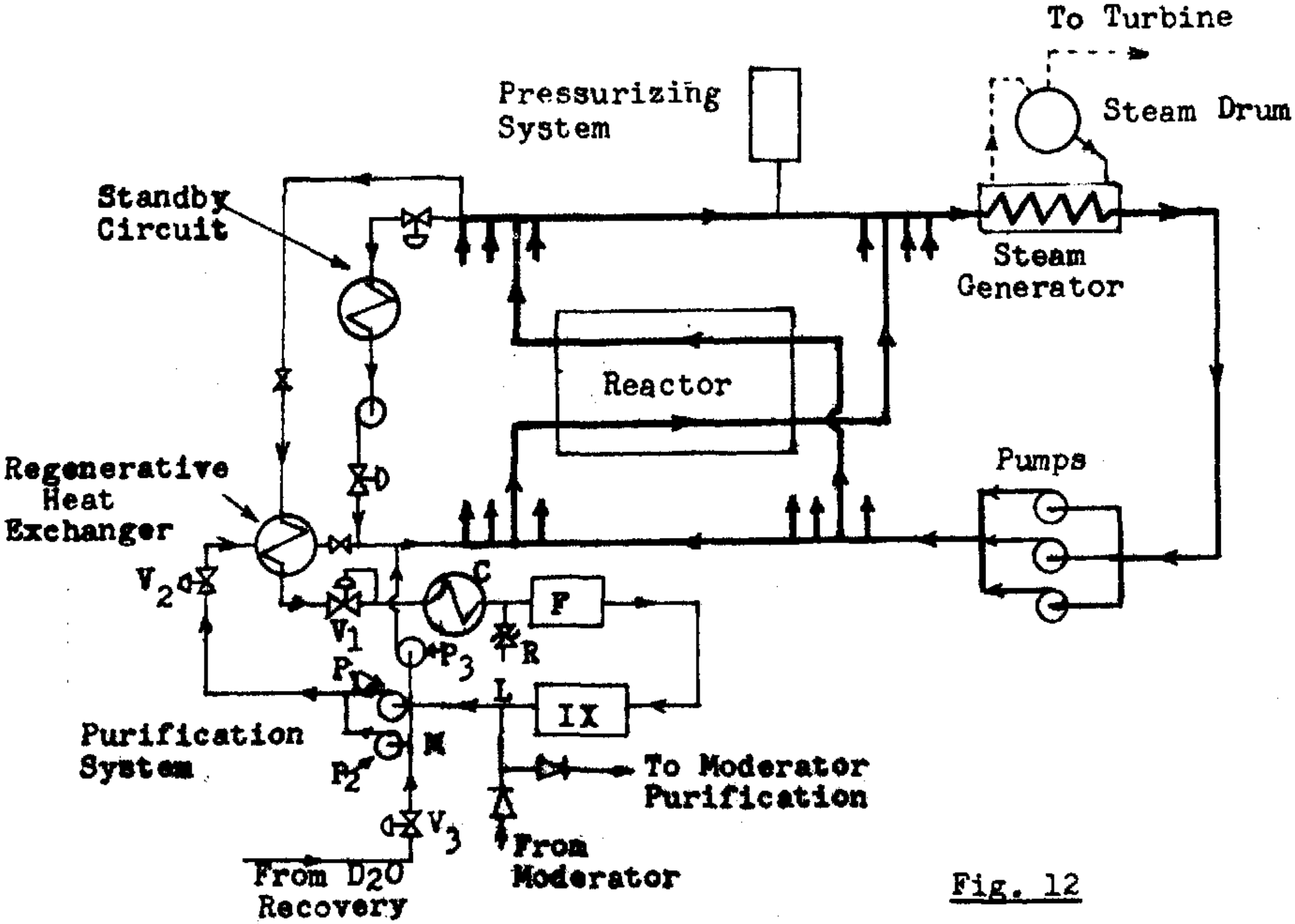

Fig. 12

Should a serious rupture occur in a heavy water heat transport system, it is preferrable to provide emergency injection of heavy water from the moderator system, to avoid serious downgrading of the system. The arrangement in Figure 12 can be used for such a purpose. A third high capacity pump, P_3, (e.g. 160 Igpm) starts on abnormally low pressurizing tank level, to provide the additional make-up volume required. This pump feeds directly into the inlet headers to avoid flow restricition in V_2. The heavy water leaking out of the system is directed, through drain lines, to a recovery system. It can then be pumped back into the moderator system to complete the cycle. Alternatively it may be pumped directly from the recovery system to the suction of P_1, P_2, and P_3 at the point M in Figure 12. Once such a cycle has been established it can continue until the heavy water supply is exhausted because of losses through seepage etc.

If the rupture is too severe for the above system to cope with, a light water injection system, feeding directly into the inlet and outlet headers as in Figure 11, may be required. Light water flow would probably be initiated by low pressure in the heat transport system while the system was still at high temperature.

If the system is pressurized with a feed and bleed system, there are no facilities, such as those described above, for heavy water emergency injection. Connections would therefore be required between the moderator system and either the headers or the charging system for this purpose. Flow to the moderator system would be prevented by check valves. Loss of pressure in the heat transport system, due to a serious rupture, would allow flow of moderator water into the heat transport system. Again a complete cycle would be set up by collecting the water, leaking out of the system, in a recovery sump and pumping it back into the moderator system. Heavy water losses will still occur through seepage and evaporation and provisions would therefore be made to have an alternative light water supply available.

Pressure Relief

Overpressurization of the heat transport system can occur as a result of :-

(a) Failure of the pressurizing system e.g. the heaters are not turned off when the pressure set point is reached.

(b) Failure of the injection, (or charging), pumps described above to shut off.

(c) Overpressurization during pressure testing due to failure of a pressure reducing valve on the pressurizing gas cylinder.

(d) Abnormal rise in reactor power.

It is considered that triplicated reactor regulating and protective systems provide sufficient safeguards against the occurrence of (d). It may also be argued that, under such conditions, the reactor core, is safer without safety valves connected directly to a pressurized heat transport system, since rapid ejection of fluid through large capacity safety valves may result in lack of heat removal from and consequent melting of the fuel. There is, however, a link between the source of power and the atmosphere through the steam generator, across to the steam side and out through the steam safety valves. About 125% of normal full power can be removed in this manner and this would be considered sufficient since the protective system trips the reactor at 110% of normal full power.

A direct cycle system would of course, be protected from possible overpower by safety valves, but direct overpressure relief in a pressurized indirect cycle system would only be provided incase of overpressurization by causes (a), (b) or (c).

In a solid system, connections can be made from the headers, through pressure relief valves R and S, shown in Figure 13, to a surge cooler A. Flashing steam and water passes into the surge cooler and the steam is condensed. The liquid is collected in the surge receiver B, which is drained when this becomes necessary. Provisions would have to be made to dispose of non-condensible gasses through the ventillation exhaust system. These non-condensible gasses would pass through a delay tank incase they contained fission product gasses and through driers if it was necessary to recover heavy water vapour.

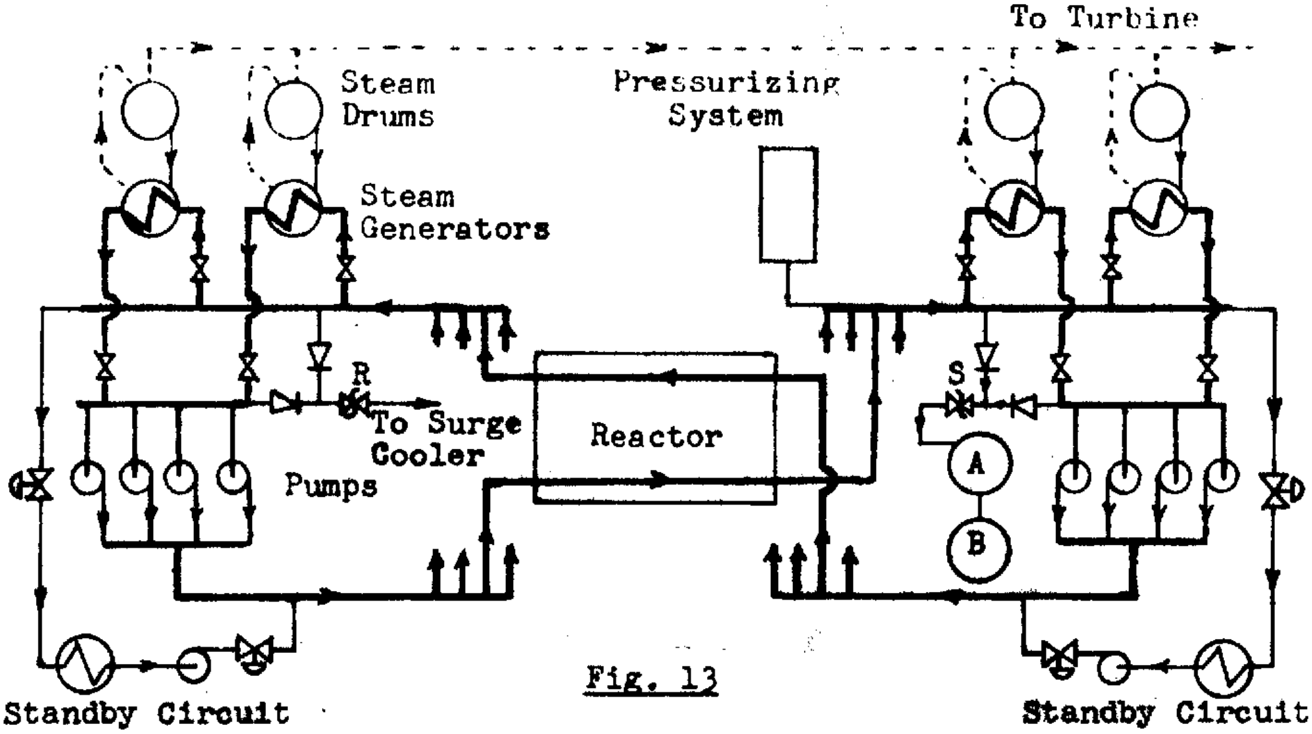

Fig. 13

If the heat transport system is pressurized by means of a vapour space produced in a pressurizing tank, the pressure relief valve is most conveniently connected directly to the tank. Vapour relieving through such a valve must be condensed in a cooler, particularly if it is heavy water vapour. It has been mentioned that such a pressurizing tank may also be used as a degassifier and vapour and non-condensible gasses are discharged from it periodically. This gaseous discharge should also go through the same cooler so that the vapours are condensed. A typical arrangement is that shown in Figure 14. The gas and vapour mixture enter the condenser where the vapour is condensed. The condensed liquid passes into the collection system through the steam traps. The non-condensible gasses are periodically released through the valve A, overpressurization of the condenser being prevented by the relief valve B. On being released, the non-condensible gasses pass through a drier, (probably containing silica gel), to the delay tank where the radioactive gasses decay. A continuous bleed from the delay tank to the ventillation exhaust can be arranged through the orifice O. The orifice O can be replaced with a remotely operated valve for periodic release of gasses from the tank. Overpressurization of the delay tank is prevented by means of the relief valve C. Condensation in the delay tank or the ventillation exhaust suction could cause a vacuum to be formed in the delay tank, which could cause the tank to collapse. This is prevented by the vacuum breaker D.

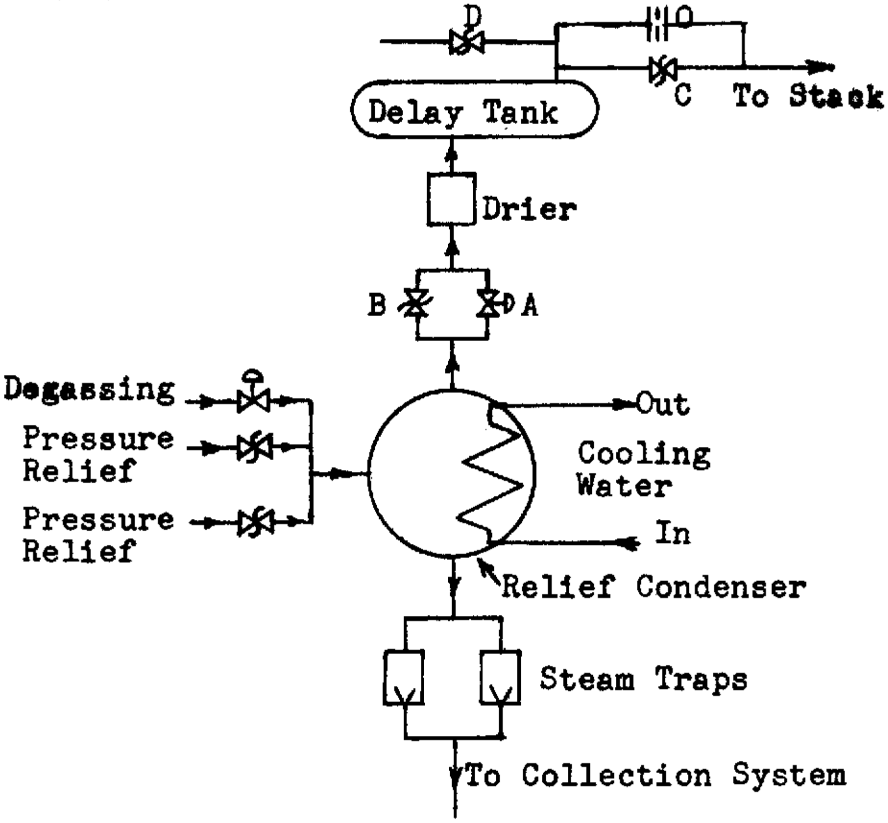

Fig. 14

Provisions can be made for relieving pressure at several locations into this system, e.g. pressure relief in the purification system, immediately ahead of the filters and ion exchange columns.

ASSIGNMENT

1. (a) Under what possible circumstances may standby cooling have to be provided?

   (b) Why is a standby cooling system not considered a back-up to the heat transport system?

2. What are the heat removal requirements of a standby system:

   (a) under normal conditions?

   (b) under emergency conditions?

   Explain your answers.

3. What conditions must exist in the main system before the standby system can be put into operation and why?

4. What are the principal design requirements of a heat transport purification system and how are these requirements met in a by-pass system.

5. Explain why degassing facilities may be required with a pressurized water heat transport fluid and explain what disadvantages such a degassing system may have.

6. How can a feed-and-bleed pressurizing system be also used for purification and degassing?

7. What purification or degassing is required and why:-

   (a) in an organic system?

   (b) in a liquid sodium system?

8. Under what circumstances could fuel in a reactor become uncovered?

9. (a) Explain what principles must be applied to a system designed to maintain a constant volume in a pressure tube reactor system and show how the purification system can be modified for this purpose.

9. (b) What further modification is required to provide emergency heavy water injection.

10. (a) Pressure relief in the heat transport system is provided to prevent overpressurization due to three possible causes. What are these possible causes?

    (b) Why is protection against overpressurization, due to abnormal rise in reactor power, not provided by direct relief? What alternative protection is provided?

11. What are the basic principles incorporated into the design of a pressure relief system for a D_2O system?

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